PROPULSION POTENTIAL OF THE ULTRAFAST Z-PINCH

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The ultrafast z-pinch has recently come back as one of the most promising approaches towards the controlled release of thermonuclear energy.

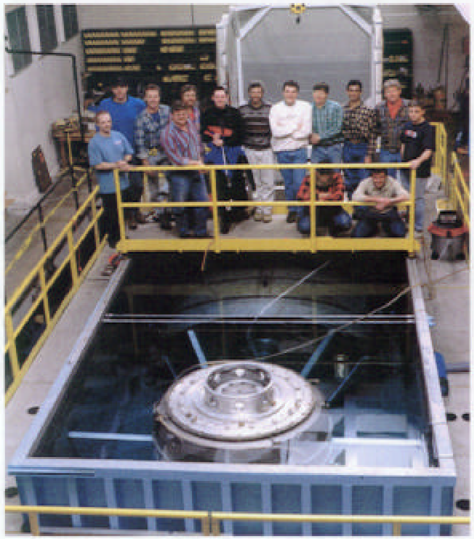
A pinch formed by the implosion of an array of thin wires is a powerful soft X-ray source, suitable to drive hohlraum thermonuclear microexplosion charges. It is an inexpensive alternative to laser driven hohlraum targets. More important for the propulsion. is that it requires much less mass. Improved concepts towards this goal will be presented.

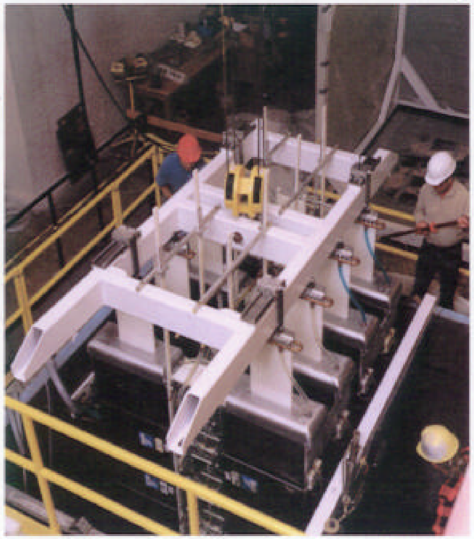
Still more exciting is the idea to ignite a thermonuclear detonation wave propagating along the pinch discharge channel, with the pinch stabilized by axial and rotational shear flow. This concept has the potential for a low yield, but high gain, thermonuclear rnicroexplosion, as it is mandated for an efficient propulsion system.

The NTF is housed in the 120,000 sq. ft. SAGE building

Zebra drives terawatt pulses through tiny loads, producing hot, dense plasma for energy research

NTF

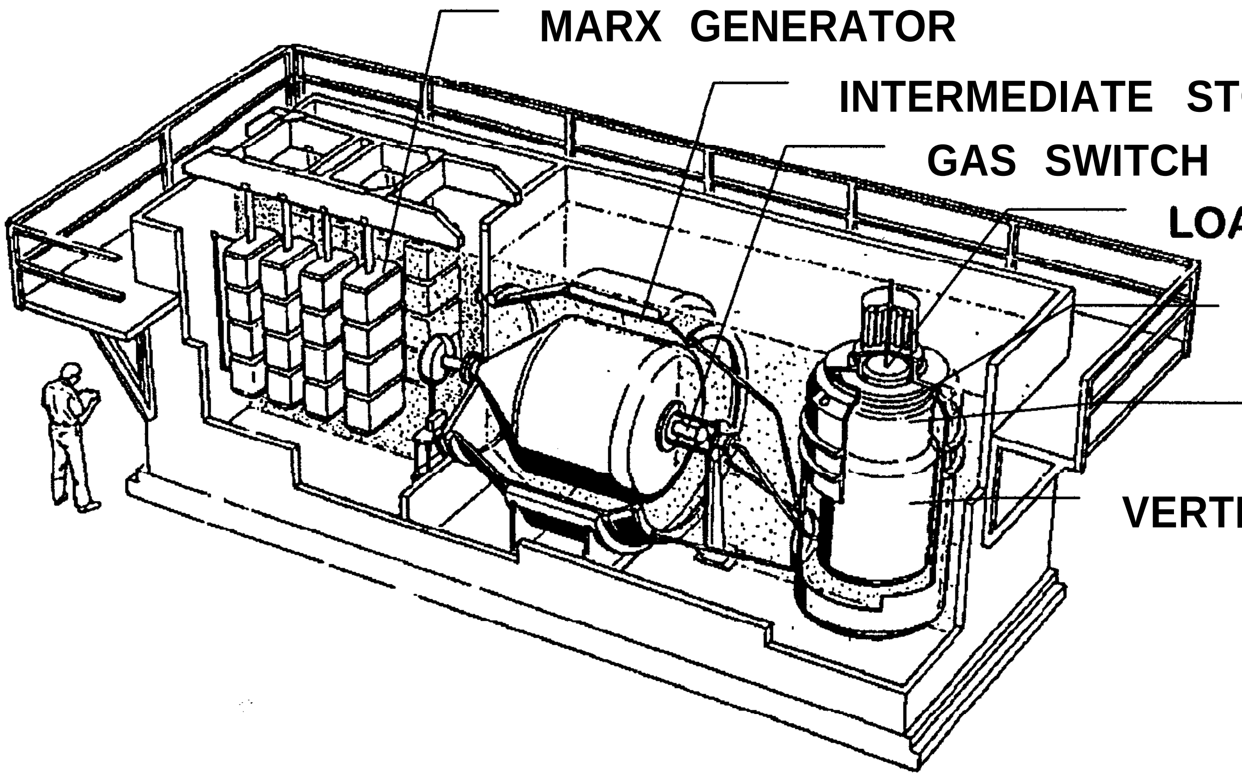




Zebra at the Nevada Terawatt Facility, University of Nevada, Reno

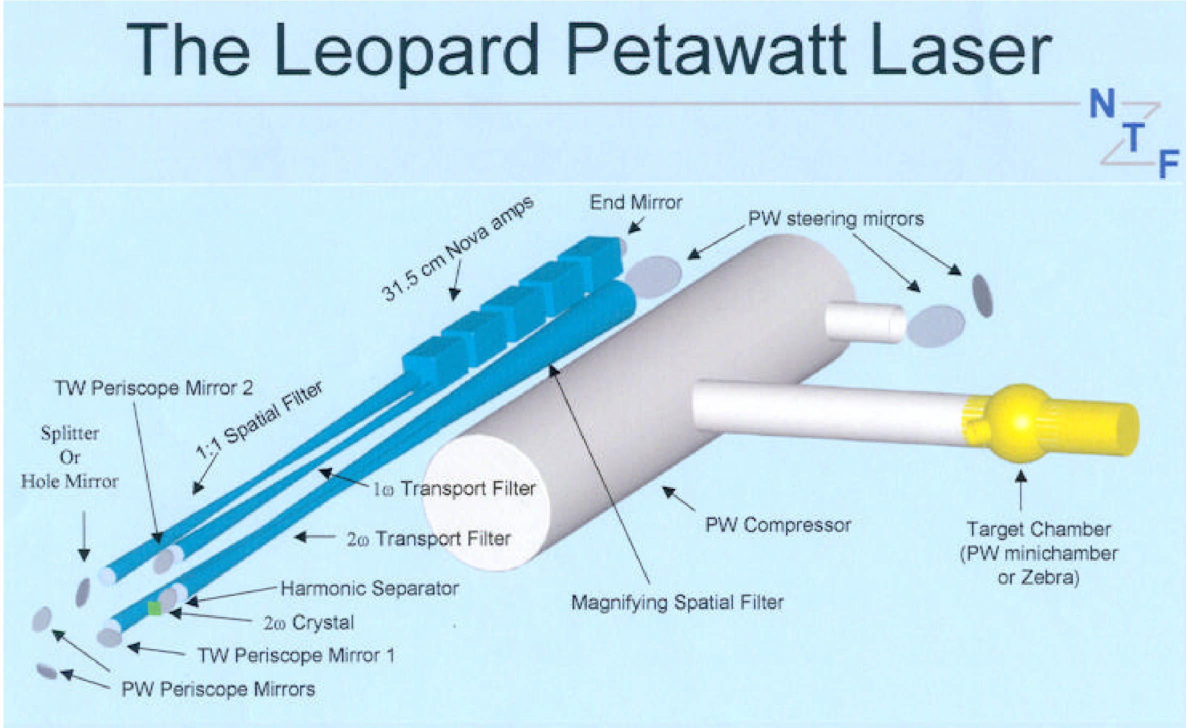
Lake Tahoe

One terawatt is being delivered to the load



Output voltage	2MV
Impedance	1.9 Ω
Load current	1 MA
Current rise-time	70 ns

Charging voltage	100 kV
Stored energy	200 kJ


The Leopard Petawatt Laser
NTF
End Mirror
PW steering mirrors
31.5 cm Nova amps
TW Periscope Mirror 2
1:1 Spatial Filter
Splitter
Or
Hole Mirror
1ω Transport Filter
2ω Transport Filter
PW Compressor
Target Chamber
(PW minichamber
or Zebra)
Harmonic Separator
2ω Crystal
Magnifying Spatial Filter
TW Periscope Mirror 1
PW Periscope Mirrors

Petawatt-lit Zebra-compressed loads could approach fusion conditions

1. **Cylindrically compress a liquid-D_2-filled liner 10-20 fold with 1 MA current, balancing Fermi-degenerate electron pressure with jxB force**
   a) 600 μm diameter → 60 μm diameter, ρ - 100 ρ_{liq}, B ~ 3 kT
   $p \sim 0.05 n_e^{5/3} h^2/m \sim B^2/\mu_0$ - 0.3 Gbar
   b) 400 μm diameter → 20 μm diameter, ρ - 400 ρ_{liq}, B ~ 10 kT
   p - $0.05 n_e^{5/3} h^2/m \sim B^2/\mu_0$ - 3 Gbar

2. **Deposit 680-J Petawatt into 18-μm-long (l = 2 x FWHM) Compressed liner segment (volume $l\pi R^2$)**
   a) $T = E/3nl\pi R^2$ - 5 keV, $\tau \sim l/2c_s$ - (9 μm)/(0.6 μm/ps) - 15 ps
   $n\tau \sim$ (5×10^{24} cm^{-3})(1.5×10^{-11} s) - 0.8×10^{14} cm^{-3}s
   b) $T = E/3nl\pi R^2 \sim$ 10 keV, $\tau \sim l/2c_s \sim$ (9 μm)/(0.9 μm/ps) ~ 10 ps
   $n\tau$ - (2×10^{25} cm^{-3})(1×10^{-11} s) - 2×10^{14} cm^{-3}s

Z-pinches offer advantages for fast-ignition fusion

- **Inexpensive *jxB* compression of DT to $\rho \sim 500\ \rho_{liq}$ possible**
  - **20x cylindrical liner compression**
  - **8x quasispherical compression (as on Shiva Star)**
  - **radiative cooling => quasi-isothermal compression ("radiative collapse" above Pease-Braginskii current)**

- **Relativistic electron confinement localizes Petawatt energy deposition: Larmor $r_{Le} = \gamma m_0 v/eB \sim (1.7\ \mu m)\gamma/B$[kT]**
  - ⇨ **micron-sized relativistic electron orbits**
  - ⇨ **heated volume shrinks (from $[100\ \mu m]^3$ to $[10\ \mu m]^3$?)**
  - ⇨ **ignition energy is reduced (1000 times?)**

- **a-particle confinement reduces ρR required for ignition (by 🗁🗀 times?) and propagating burn (by 3.5 times?)**

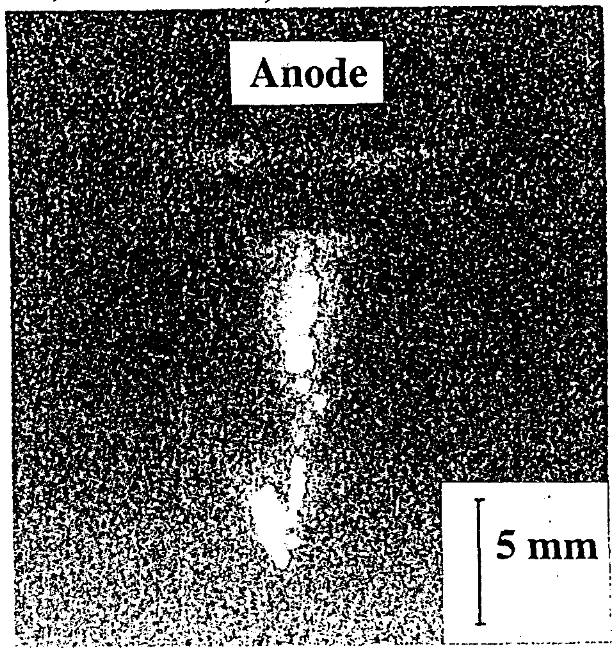
- **Long propagating burn => high gain & D_2 fusion fuel**

Certain load configurations might help achieve better stability

- Stabilization effects to be studied include:
  - ◆ axial velocity shear
  - ◆ azimuthal velocity shear
  - ◆ seeded axial magnetic field
  - ◆ initial density profile
  - ◆ finite Larmor radius effects
  - ◆ Hall effect

The First Time-integrated X-ray Image of a Ti Z-pinch Plasma at the NTF

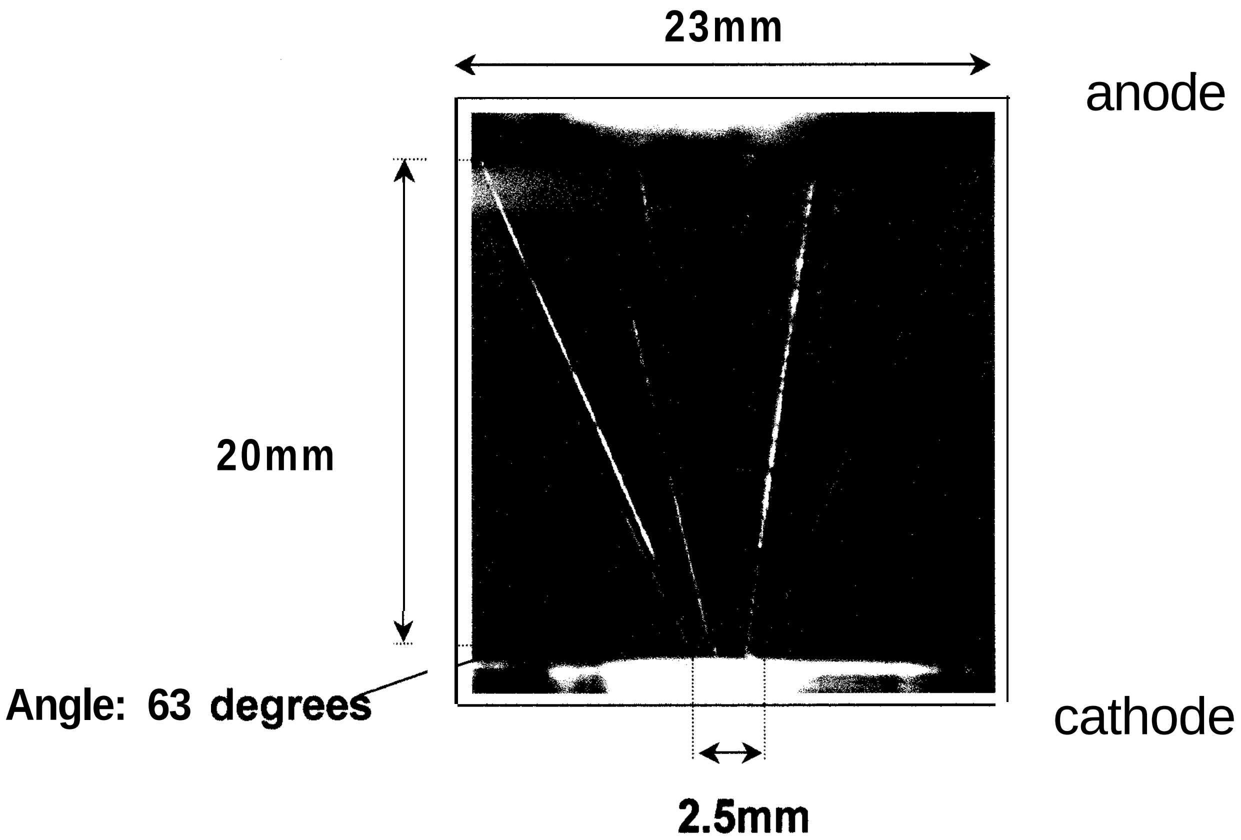
Z-pinch: I,, > 700 kA; $\tau_{1/2}$= 80-85 ns
Load: Ti wire (φ = 20, 32 μm; L = 14 mm)



Pinhole Camera: φ = 100 mm; Au Foil Thickness d = 120 μm; Magnification M = -4.5;
Distance from Plasma a = 528 mm; Resolution R_{res}= 550 μm; Filter:
100 μm Be + 6 μm mylar + 0.2 μm Al; Cutoff Wavelength $\lambda_{0.1} \leq$ 6.5 Å or $\lambda_e \leq$ 13 Å
X-ray Film: UFSH-S (one layer)

View of Lake Tahoe from High Camp • Squaw Valley

Conical arrays help us study shear flow stabilization



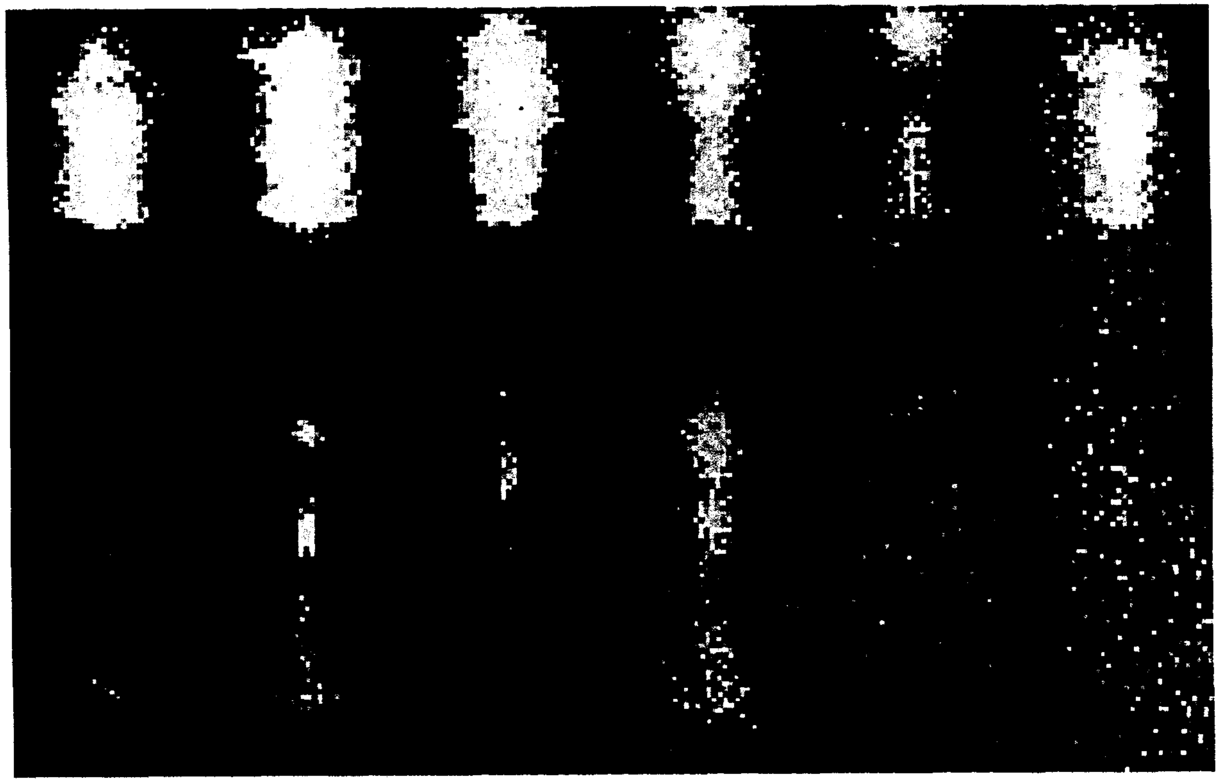
1 central 152 pm diameter Ti wire + 8 outer 15.2 μm diameter Al wires

Current: 1 MA, 70ns from 10% to 90%, 120 ns from 0 to max

Time-gated x-ray image of Al on Ti conical array z-pinch (03/08/01)

Al

Ti



6 5 4 3 2 1

Interframe At = 8 ns

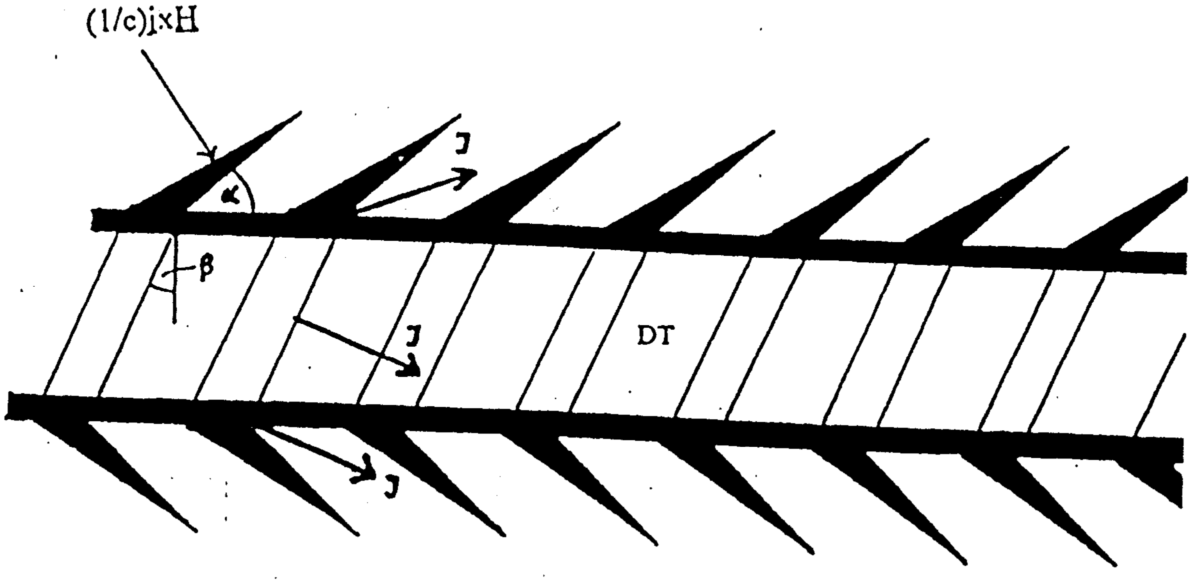


Figure 1. Corrugated capillary tube filled with solid DT: a wedge angle, β pitch angle of corrugated surface, J j et, (1 lc) j x H magnetic body force.

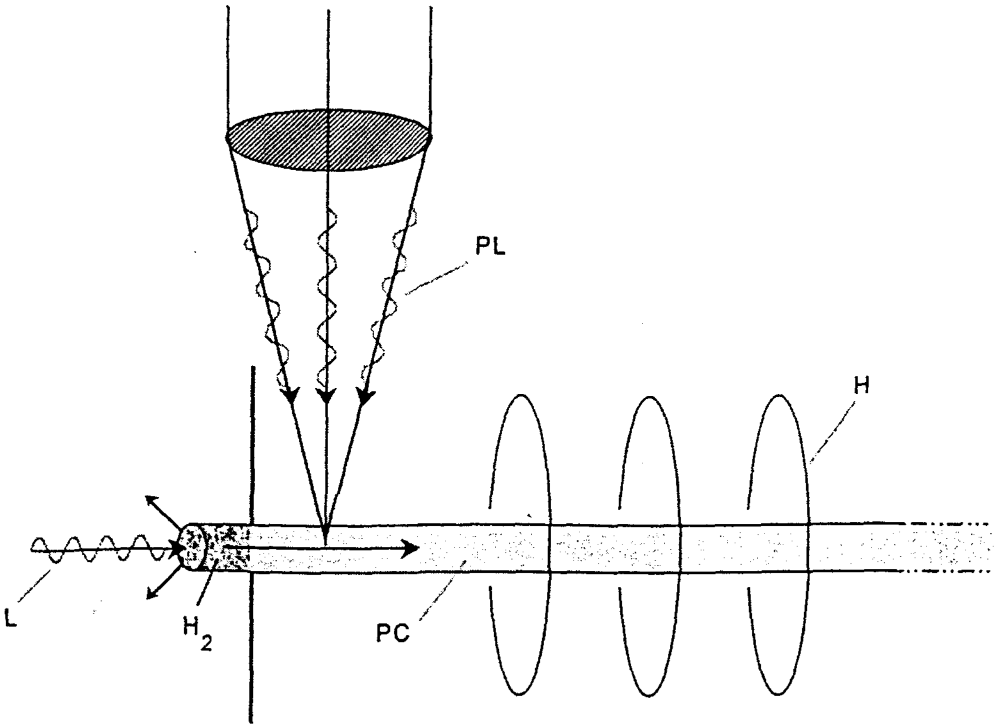


Fig. 1. Fusion chain reaction in axial shear Row stabilized z-pinch. PC, pinch channel; H, magnetic field; H_2, solid hydrogen as dense jet propelled into PC by laser L or particle beam ablation rocket propulsion; PL, focussed petawatt laser beam for ignition.

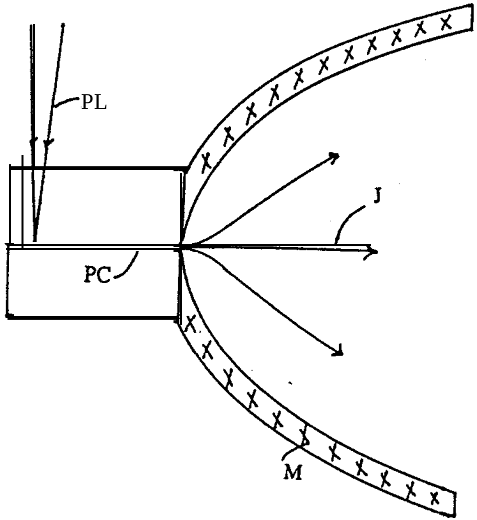


Fig. 2. Pinch propulsion concept. PC, pinch channel; J, plasma exhaust jet; PL, petawatt laser beam; M, magnetic reflector.